The Models of Centrifugal Governors in the Collection of Bauman Moscow State Technical University

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Abstract. In the period of development of higher technical education great importance was given to the visibility in training of engineers. This was realized with the help of models of machines and mechanisms. Collections of models of mechanisms were formed practically in every engineering school. This article describes the collection of centrifugal governors of BMSTU collected at the end of the 19th century. Some models were brought from Europe; others were designed and manufactured in the school (IMTS). The article gives a brief description of some models and basic principles of their operating (operation); it also provides information on the history of their creation and production.

Key words: history of the science and mechanisms, theory of the regulation, steam engine, centrifugal governor, model of mechanism, 3D model

1 Introduction

Organization of training courses that were included into the discipline of Applied Mechanics occurred in the 1970s. In different universities curriculums were different. In the Moscow University (MSU) and Imperial Moscow Technical School (IMTS) these courses were created by Orlov [7]. In IMTS at the department of Applied Mechanics future engineers were read: the theory of machines, the theory of mechanisms, hydraulics, thermodynamics, strength of materials and theory of steam engines. The course of the theory of steam engines was high demanded at that time, and theory of regulating was an important part of that course. This course provided a description of various models of centrifugal governors and the basics of their theory. Models of centrifugal governors of various designs were manufactured in the workshops of IMTS and purchased in Germany for demonstrations on lectures and study on the practical lessons. Some of these models survived to this day.

This article deals with these models, provides an analysis of their design and classification, describes the results of animation of these models based on 3D modeling.

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Fig. 1 Steam engine from Munich museum. Photo was taken by V. Tarabarin.

2 Regulation of the Steam Engines

It is known that the steam engine is an external combustion heat engine that converts the energy of hot steam into mechanical work (Figure 1).

In the drive of steam engine driving force and external loads vary both within one cycle and for longer periods of time. Uneven rotation of shaft of the machine causes additional dynamic loads and affects the quality of products. E.g., in the textile industry this leads to uneven thickness of the thread or to its breakage, in process of cutting this leads to increase of surface roughness and to reduction of accuracy [9]. Control devices are used to reduce the unevenness of the rotation, they are: flywheels, which accumulate kinetic energy and reduce the fluctuation of the velocity inside the cycle, and centrifugal governors, which maintain constancy of the speed at longer intervals.

For the first time governors have been used to regulate distances and efforts between millstones of windmills and watermills. In 1788 Scottish engineer James Watt [5, 10, 11] applied such a governor to maintain the uniformity of rotation of the shaft of the steam engine. The classic Watt's governor is a centrifugal governor of direct action, because the movement of coupling has direct impact on the value of the driving force, decreasing or increasing the amount of steam (Figure 2).

3 Types of Centrifugal Governors

According to the operating principle regulators are divided into static, astatic and pseudoastatic. The last were later developed based on astatic to eliminate their shortcomings [3, 7, 10]. Static governors are such governors, where each value of shaft speed corresponds to its equilibrium position of loads and coupling. In astatic governor loads and coupling will be in equilibrium only at one value of the velocity of

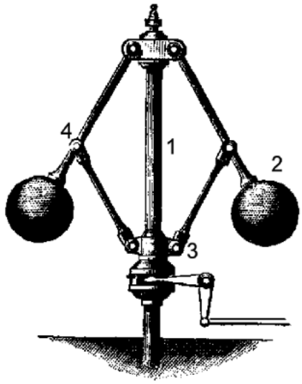


Fig. 2 Watt's centrifugal governor, where 1 – shaft, 2 – loads, 3 – coupling, 4 – lever arms.

the shaft in any possible position of governor elements. At a speed different from the specified value equilibrium is impossible.

Let us consider classic Watt's centrifugal governor. In the initial position of the governor the shaft rotates at some constant speed ω_0, at the same time the moment of the centrifugal force cannot overcome the moment of gravity forces of loads 2 and the coupling 3. With the increasing speed the moment of the centrifugal force increases, exceeds the moment of gravity forces and turns levers 4, moving up loads 2 and coupling 3. Moving of the coupling leads to the displacement of control levers and reduction of steam. As a result, rotation speed of the shaft begins to decline and loads and coupling move down. In addition to the gravity forces and inertial forces there are the forces of friction, acting on the elements. Under their action coupling stops above or below the final position for a given shaft speed. The greater the difference between actual and desired position of coupling, the more the actual speed differs from the nominal value. Obviously, the speed range corresponding to equilibrium positions of the governor should be as small as possible. This reduces the regulation error and unevenness of rotation.

Watt's classic static governor has a large range of equilibrium and is highly uneven. However, it has been widely spread and successfully worked in steam engines of small capacity. Many scientists and inventors were engaged in its improvement and created its new structural varieties.

One of these scientists was the great Russian mathematician and engineer Chebyshev [1, 2]. In his writings Chebyshev develops a method of determining basic sizes of Watt's governor in order to achieve the best astatic characteristics while maintaining the original simplicity of design. For optimal results, he designs levers of complex shape with variable width and radius of curvature. Governors designed by Chebyshev were produced in IMTS workshops. Two of these models are preserved in the collection of BMSTU.

There are also fully astatic governors. E.g., Garnett's governor, in which astatic characteristics are achieved by design features [7, 11]. Loads are attached to a firm

a b

Fig. 3 (a) Chebyshev's centrifugal governor, (b) another Chebyshev's centrifugal governor from the collection of BMSTU.

rail frame, which provides a parabolic path of their movement (Figure 4a). The same principle is realized in the model of another governor, where a heavy coupling is designed in a form of a cover, the inner part of which serves as the sideways for the path of divergent loads (Figure 4b).

It may seem that astatic governors, allowing only one equilibrium speed, are very convenient in practice. However, in the process of regulating their coupling always slipped equilibrium, and the governor performed, in fact, oscillatory motion, which was totally unacceptable. Thus, the desire to get complete astatic characteristic was a mistake.

Speaking about inapplicability of astatic regulators it is necessary to mention another great Russian mathematician and engineer Vyshnegradsky [4, 5].

He came to a conclusion that the governor without introducing additional elastic forces and forces of friction (provided by a spring or cataract), cannot provide good movement regulation. Astatic regulators are absolutely not suitable even when using these devices. Pseudoastatic governors turned up to be the best for practical application, which replaced static ones and became popular.

Pseudoastatic governors combined a sufficient stability of static governors (each configuration corresponding its equilibrium rate), and thus they allowed only minor variations of adjustable speed. The design of pseudoastatic governors provides various ways of reduction of velocity fluctuations.

The first pseudoastatic governor from BMSTU collection is Kley's governor (Figure 5a). This model is characterized by intersecting rods. Such construction realizes a simple, but effective mechanism of reduction of velocity fluctuations. The disadvantage of this model is its large size.

Pröll's governor (Figure 5b) is a successful modification of Kley's governor, providing the same small speed variations at twice smaller sizes. The upper lever arms are bent, to provide the free movement of loads, coupling has large mass and pear-shaped form.

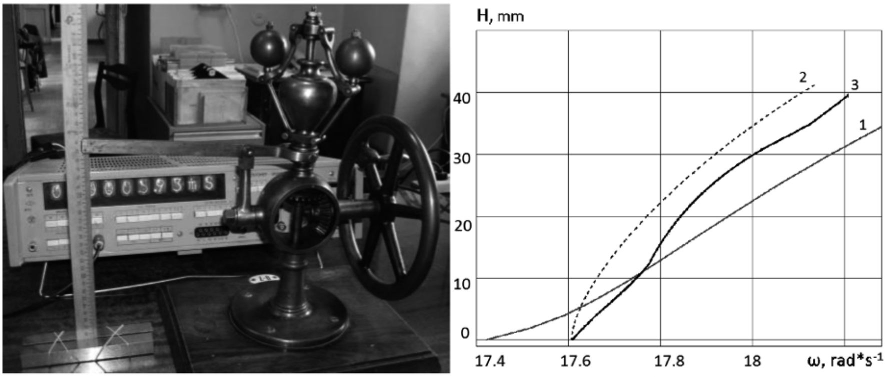
a b c

Fig. 4 (a) Garnett's centrifugal governor, (b) the governor with the massive cover-like muff, (c) centrifugal governor with massive ring. Governors are from the collection of BMSTU.

a b

Fig. 5 (a) Kley's centrifugal governor, (b) Pröll's centrifugal governor. Governors are from the collection of BMSTU.

The collection of BMSTU contains an original design of centrifugal governor, which was produced using drawing of Redtenbacher [8]. The inertial element of this governor has a shape of a massive ring (Figure 4c). There is a groove in the upper part of the ring at the arc of approximately 160°; this lightens one side of the ring. As a result, in the static position the ring is located with a slight slope to the vertical axis. With increasing frequency of rotation of the shaft inertia forces turn the ring around the horizontal axis and it turns into horizontal position. The model is designed and manufactured in 1862 by Ivanov Pavel, Moscow Craft School (MCS) student.



a b

Fig. 6 (a) Research facility, (b) theoretical diagrams, where 1 – diagram for Watt's governor, 2 – diagram for Pröll's governor, 3 – experimental diagram.

4 Experimental Characterizations

Models of mechanisms were used in the training not only for the demonstration at lectures and seminars. It served as objects for technical drawing and sketching, for experimental studies. To verify this application of models authors conducted an experimental determination of the working characteristics of one of the models of governors. Pröll's governor was used as the object of research (Figure 6a). Since it was impossible to equip a model with an engine which could produce a variable speed, then the following experimental method was used. At the end of the lever clutch control a vertical ruler was installed. To measure the frequency of the shaft controller we used a frequency chronometer F5041, a signal voltage of 1.5 volts from alkaline battery was supplied to its input. The circuit was opened with plate spring, which contacted with the tops of the teeth of a bevel wheel controller. During the experiment, the model speed was set by hand, providing the movement of the coupling from lower to upper position. In front of the facility a digital camera was installed, which was used to photograph the facility, so that you can determine the position of the lever clutch and the frequency meter readings in the photo. Photography was done randomly, until there were a sufficient number of points to build a diagram.

Using the experiment results we built the working characteristics and compared them with the calculated characteristics (Figure 6b). The analysis showed a minor difference between the experimental and the theoretical characteristics [10]. Moreover, theoretical curves were compared with the Watt's governor. Pröll's governor has a smaller range of equilibrium rates and steeper performance.

a b c

Fig. 7 3-D models of: (a) Pröll's governor, (b) Garnett's governor, (c) Chebyshev's governor.

5 Computer 3D Modelling of Governors

In modern world of multimedia systems of distance studying practical application of full-scaled physical models becomes impossible. Here we can successfully use their photos and video fragments. In a relatively short period of time (about 50 years) the collections of models in the majority of technical universities were lost. Interest in saving the collections appeared about 15 years ago [6], however, the problem of saving the collections of models exists today. There are large collections of models in technical museums of London, Paris, Munich and Moscow, but they are often stored in vaults and not available for visitors. Also we should not forget about their fragility and uniqueness, many models survived only in single copy. With the development of computer technologies it has become possible to create 3D models and films, based on these models. Such films are useful in lectures-presentations, as they are compact and well understood. They can demonstrate models in motion, show it in perspective, and demonstrate the assembly of model from individual parts. Storing 3D models on digital media allows you to keep the models themselves, as well as translate them into drawings and make copies. In this work some governors were recreated in 3D models. The development of this project is done via software Autodesk Inventor 2010. A library of components was created for each governor – bases, loads, rods, gears, fasteners and so on. From these elements the whole models were assembled, that fully reproduce the mechanisms (Figure 7).

6 Conclusions

Centrifugal governors were among the first mechanical systems of automatic control. They are important monuments of history of technology, historical background of creation of theory of regulating. The study of their constructions, ways of their

development, principles of regulating embodied in them is important not only for history of science and technology. Models of the governors demonstrate the level of design and manufacturing of engineering products in the mid-19th century, technological capabilities of small-batch production. They are interesting object to study engineering ideas of the era of steam engines.

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